Faculty of Mechanical Engineering

PHYSICO-MECHANICAL PROPERTIES OF HYBRID CROSS PLY BANANA/GLASS FIBRE REINFORCED POLYPROPYLENE COMPOSITES

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Master of Science in Mechanical Engineering

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**A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
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2020

DECLARATION

I declare that this thesis entitled “Physico-mechanical Properties of Hybrid Cross Ply Banana/Glass Fibre Reinforced Polypropylene Composites” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature	:	……………………….
Name	:	Norizzati binti Zulkafli
Date	:	……………………….

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature	:	…………………………………………………………….
Supervisor Name	:	Associate Professor Dr. Sivakumar A/L Dhar Malingam
Date	:	…………………………………………………………….

DEDICATION

To my beloved parent, Asmah binti Md Nor and Zulkafli bin Baharuddin.

ABSTRACT

To date, the increasing awareness towards a green future has brought a many recyclable and biodegradable things into our daily lifestyle. The ever-increasing demand of green composite will continue to grow with the desire for stronger and lighter materials. However, natural fibres as reinforcement are insufficient to satisfy the technical needs of a composite. Therefore, embedding commonly available E-glass fibre into banana fibre reinforced composite will enhance the overall properties. For this reasons, natural fibres considered as one of the alternatives in reducing the impact on environment in terms of renewability, recyclability, biodegradability, sustainability, health and eco-friendly. Banana fibre is used in this research, however limited research on the hybrid cross-ply banana/glass fibre reinforced polypropylene (PP) composite are available. Thus, this research aims to determine the effect of fibre lay-up sequence on the mechanical, physical properties and effect of moisture absorption on the mechanical properties. The mechanical properties comprise of tensile, flexural, quasi-static indentation and low-velocity impact and comparison between dry and wetted specimens of tensile and flexural tests. Both cross-ply banana (B) and glass (G) fibre were cut into dimensions of 250 x 250 mm and stacked alternately with polypropylene sheets. The four different lay-up sequences of composites (BBB, BGB, GBG and GGG) were hot pressed and cut into test dimensions according to ASTM standards with thickness determined by ply stacking lay-up. Tensile and flexural tests were done according to ASTM D3039 and ASTM D790 respectively with speed rate of 2 mm/min. Quasi-static indentation (QSI) and low-velocity impact (LVI) tests were done according to ASTM D6264 and ASTM D7136 respectively. The speed rate for QSI is 1.27 mm/min and impact velocity speed for LVI is 4.5 m/s. The moisture absorption test is conducted according to ASTM D570. Embedding glass fibre to banana fibre reinforced composite shows promising improvement by 253.52% and 780.49% for GBG in terms of tensile strength and modulus. The incorporation of glass fibre as the skin layer improves the GBG flexural strength and modulus by 17.50% and 86.83% compared to BBB. The energy absorption for GBG also were improved by 161.27% and 188.57% for quasi-static indentation and low-velocity impact respectively. Besides, the incorporation of glass fibre reduced the moisture absorption rate by 66.99% for GBG while thickness swelling decreased by 29.01%. As for the effect of moisture on the tensile and flexural properties, the tensile strength and modulus of GBG were reduced by 1.34% and 16.34% when compared to dry samples. Contradict with the tensile properties, the flexural strength and modulus of wetted GBG increased by 13.07% and 12.50% respectively. In terms of lay-up sequence, the wetted tensile strength and modulus of GBG increased from BBB by 439.74% and 978.57%. Flexural strength and modulus also increased from BBB to GBG by 46.43% and 126.45% respectively. The results showed that hybrid banana/glass fibre reinforced polypropylene composite can be commercialized for mid-range load applications.

ABSTRAK

Sehingga kini, kesedaran berkaitan masa depan hijau telah menyebabkan masyarakat mempraktikkan kitar semula dan menggunakan barang biodegradasi. Permintaan komposit hijau yang semakin meningkat akan terus berkembang dengan permintaan bahan yang lebih kuat dan ringan. Walaubagaimanapun, serat gentian semulajadi sebagai pengukuhan adalah tidak mencukupi untuk memenuhi keperluan teknikal sesuatu komposit. Oleh itu, memasukkan serat kaca jenis E didalam komposit bertetulang gentian batang pisang akan meningkatkan sifat keseluruhannya. Atas sebab ini, serat gentian semulajadi dianggap sebagai salah satu alternatif dalam mengurangkan kesan terhadap alam sekitar dari segi pembaharuan, kitar semula, biodegradasi, kelestarian, kesihatan dan mesra alam. Serat batang pisang digunakan dalam penyelidikan ini, tetapi kajian berkaitan komposit hibrid polipropilena bertetulang serat gentian batang pisang/kaca adalah terhad. Oleh itu, kajian ini bertujuan untuk menentukan kesan susun atur serat pada sifat mekanikal, fizikal dan kesan penyerapan kelembapan pada sifat-sifat mekanikal. Ciri-ciri mekanikal terdiri daripada lekukan tegangan, lenturan, lekukan kuasi statik dan kesan kelajuan rendah dan perbandingan antara spesimen tegangan dan lenturan kering dan basah. Kedua-dua serat silang batang pisang (B) dan kaca (G) dipotong mengikut dimensi 250 x 250 mm dan disusun secara bergantian dengan kepingan polipropilena. Empat susunan susunan komposit yang berlainan (BBB, BGB, GBG dan GGG) difabrikasi menggunakan mesin "hot press" dan dipotong mengikut dimensi masing-masing berdasarkan piawaian ASTM dengan ketebalan ditentukan oleh susunan serat di dalam komposit. Ujian tegangan dan lenturan berdasarkan piawaian ASTM D3039 dan ASTM D790 dengan kadar kelajuan 2 mm/min. Ujian lekapan quasi-statik (QSI) dan kesan kelajuan rendah (LVI) telah berdasarkan piawaian ASTM D6264 dan ASTM D7136. Kadar kelajuan QSI ialah 1.27 mm/min dan kelajuan kelajuan impak untuk LVI adalah 4.5 m/s. Ujian penyerapan air berdasarkan piawaian ASTM D570. Penambahan serat kaca dalam komposit bertetulang serat batang pisang menunjukkan peningkatan sebanyak 253.52% dan 780.49% untuk GBG dari segi kekuatan dan modulus tegangan. Penggunaan gentian kaca sebagai lapisan luar komposit meningkatkan kekuatan lenturan GBG dan modulus sebanyak 17.50% dan 86.83% berbanding BBB. Penyerapan tenaga untuk GBG juga meningkat sebanyak 161.27% dan 188.57% bagi lekapan quasi statik dan kesan kelajuan rendah. Selain itu, penggabungan gentian kaca mengurangkan kadar penyerapan lembapan sebanyak 66.99% untuk GBG manakala bengkak tebal menurun sebanyak 29.01%. Bagi kesan lembapan pada sifat tegangan dan lenturan, kekuatan tegangan dan modulus GBG menurun sebanyak 1.34% dan 16.34% apabila dibandingkan dengan sampel kering. Berbeza dengan sifat tegangan, kekuatan lenturan dan modulus bagi sampel basah GBG meningkat 13.07% dan 12.50%. Dari segi susunan, kekuatan tegangan basah dan modulus GBG meningkat dari BBB sebanyak 439.74% dan 978.57%. Kekuatan dan modulus lenturan juga meningkat dari BBB kepada GBG sebanyak 46.43% dan 126.45%. Hasil menunjukkan bahawa komposit polipropilena serat gentian pisang/kaca boleh dikomersialkan untuk aplikasi beban pertengahan.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
B	-	banana
BBB	-	banana/banana/banana
BGB	-	banana/glass/banana
G	-	glass
GBG	-	glass/banana/glass
g/cm^3	-	gram per centimetre cube (density)
GGG	-	glass/glass/glass
GPa	-	Giga-Pascal
HDPE	-	high density polyethylene
J	-	Joule
kN	-	kilo-Newton
LVI	-	Low-velocity Impact
mm	-	millimetre
mm/min	-	millimetre per minute
MPa	-	Mega Pascal
m/s	-	metre per second
N	-	Newton
NaOH	-	Natrium Hydroxide / Sodium Hydroxide
PP	-	Polypropylene
QSI	-	Quasi-static Indentation
SEM	-	Scanning Electron Microscopy
V_f	-	volume fraction
wt%	-	weight percentage
℃	-	degree Celsius

LIST OF PUBLICATIONS

JOURNAL:

1. Zulkafli, N., Sivakumar, D., Fadzullah, S. H. S. M., and Razali, N., 2019. Quasi and dynamic impact performance of hybrid cross-ply banana/glass fibre reinforced polypropylene composites. *Materials Research Express*, 6(12), pp. 1-21.

2. Zulkafli, N., Sivakumar, D., Fadzullah, S. H. S. M., Mustafa, Z., Zakaria, K. A., and Subramonian, S., 2019. Effect of water absorption on the mechanical properties of cross-ply hybrid pseudo-stem banana/glass fibre reinforced polypropylene composite. *Materials Research Express*, 6(9), pp. 095326.

3. Zulkafli, N., Sivakumar, D., Fadzullah, S. H. S. M., Mustafa, Z., Zakaria, K. A., and Subramonian, S., 2019. Mechanical Properties of Cross-Ply Banana-Glass Fibre Reinforced Polypropylene Composites. *Defence S&T Technical Bulletin*, 12(1), pp. 124–136.

CHAPTER 1

INTRODUCTION

1.1 Background of study

The current society is facing issues with the aspect of the environment (Nallusamy and Majumdar, 2016; Bhoopathi et al., 2017), renewability, recyclability, biodegradability, sustainability, health and eco-friendliness (Sreenivasan et al., 2015). One of the reasons is due to the synthetic composites that are being used.

Composite is made up of two constituents which are matrix and reinforcement. The matrix can be categorized into three groups which are from metals, polymer and ceramics. The polymer group can be categorized as thermoplastic and thermoset. Both differ in their thermal processing behaviour where thermoplastic can be processed repeatedly while thermoset could not. This is because thermoset is chemically linked through a covalent bond which refuses to soften, creep and solvent attack. Many preceding researchers have been using thermosets as their subject of study such as E-glass/Kevlar/carbon reinforced epoxy hybrid composite (Bhudolia et al., 2018), glass/carbon/sisal reinforced epoxy composite (Arulkumar et al., 2017) and banana/sisal reinforced epoxy matrix (Venkateshwaran et al., 2011). Therefore, thermoplastic will be used in this study as it shows potential in recycling and eco-friendliness.

Many researchers, engineers and scientists have shown interests on polymeric composites with natural fibres due to its characteristics such as low cost, low density, non-abrasive to the equipment, non-irritation to the skin, reduced energy consumption and also relatively cheap (Farias et al., 2009; Sanjay et al., 2015). More importantly, natural fibres are renewable, recyclable, less health risk and eco-friendly (Gupta and Srivastava, 2016a). Natural fibres assured the future as it is sustainable in production.

However, there are several drawbacks that hinder the fibres to be fully utilized. The drawbacks of reinforcing natural fibres in a composite are due to the hydrophilic trait that makes them poor moisture resistance, high biodegradability when exposed to the environment, limited thermal stability, low modulus and strength. High moisture absorption causes dimensional changes in the fibres. The reinforcing efficiency of fibres depends on the fibre to matrix interface and the ability to transfer stress applied from matrix to fibre (Pickering et al., 2016). But this fibre to matrix interface problem can be overcome by applying chemical treatments, surface modification or reduced by hybridization (Gupta and Srivastava, 2016b).

Hybrid is defined as a composite that reinforced with a combination of two or more fibres. Hybrid can be roughly categorized into three types which are synthetic/synthetic hybrid, synthetic/natural hybrid and natural/natural hybrid. The drawbacks of natural fibres composites such as being a hydrophilic fibre, low strength and modulus, low density and low thermal resistance can be reduced by hybridizing with synthetic fibres. Moreover, based on cost efficiency, hybrids are focusing on synthetic/natural group (Saba et al., 2014).

Synthetic/natural group hybridization shows positive feedbacks as the mechanical, thermal and physical properties are enhanced. The mechanical properties of the Palmyra fibre composites are enhanced due to the incorporation of glass fibre and also reduce the maximum moisture absorption of the composites (Velmurugan and Manikandan, 2007). The mechanical properties and moisture absorption improved by hybridizing natural and synthetic fibres (Dan-mallam et al., 2015). Most of the research works on hybrid synthetic/natural fibres composites, aims to diminish the application of conventional fibres (Joshi et al., 2004). The mechanical properties of synthetic/natural fibre reinforced polyester composite are enhanced and overall strength can be increased and cost saving of more than 30% (Rafiquzzaman et al., 2016).

Banana fibre from the trunk is abundantly available as it is considered as a secondary crop. Often, the trunk was left to be decomposed after the fruit is harvested. So, the combination of glass and banana fibres in the unidirectional woven mat will greatly give more advance and enhancement in this field. In the present work, glass and banana fibre reinforced hybrid composites were fabricated by hot moulding compression method and their mechanical and physical properties have been investigated experimentally.

1.2 Problem statement

Banana fibre as reinforcement is insufficient to satisfy the technical needs of a composite. Hybridization and orientation of the fibre in the composite are among the ways that can control and improve the composite properties. Banana fibre will be hybridized with abundantly available E-glass fibre. Embedding glass fibre into banana fibre reinforced polypropylene will enhance the mechanical and physical properties of the composite. Natural fibres were known for its disadvantages of being hydrophilic. Incorporation of glass fibre into banana fibre reinforced composite will reduced the moisture absorption, thickness swelling and improved its mechanical properties. However, there are limited research on the physico-mechanical properties of hybrid cross-ply banana/glass fibre reinforced polypropylene composites.

1.3 Objectives

The general objective of this study is to investigate the physico-mechanical properties of hybrid banana/glass fibres reinforced polypropylene composites.

The specific objectives of the study are as follows:

i. To fabricate hybrid composite through fibre lay-up with orientation of 0/90º direction.
ii. To analyse the effect of fibre lay-up sequence on the mechanical and physical properties of hybrid composites.
iii. To assess the effect of moisture absorption behaviour on the tensile and flexural properties of hybrid composites.

1.4 Scope

The scope of this research is to fabricate the composite using hot compression moulding and tested to determine the effect of fibre lay-up on the mechanical and physical properties. The fibre and matrix will be stacked alternately in 0/90º direction. The mechanical properties involved are tensile, flexural, quasi-static indentation and low-velocity impact. The physical properties are moisture absorption and thickness swelling. Specimens will be prepared and mechanically tested for:

i. Tensile test. (ASTM D3039)
ii. Flexural test. (ASTM D790)
iii. Quasi-static indentation test. (ASTM D6264)
iv. Low-velocity impact test. (ASTM D7136)
v. Moisture absorption test. (ASTM D570)
vi. Thickness Swelling. (ASTM D570)

1.5 Thesis layup

Chapter 1 describes the background of the study, problem statement, objectives, scope of the study, significant of study and thesis layup. Any relevant preceding researchers are included in Chapter 2; literature review. This chapter elaborates more on synthetic, natural fibres and the related issues. The advantages and benefits of using natural fibres and literature surveys on hybrid composites are included.

Chapter 3 describes the methodology for this study. The technique in preparation, testing procedure and data collecting is briefly explained. Chapter 4 presents and elaborates on the results based on data collected. The mechanical and physical properties are discussed. Chapter 5 presents the overall conclusion and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review is prepared regarding fibre reinforced composite materials, which includes an introduction to composite materials, fibre and matrix, advantages and disadvantages of natural and glass fibres. An overview of the mechanical and physical properties of fibre reinforced, banana fibre reinforced and hybrid reinforced composites. A review on the factors affecting mechanical as well as physical properties of hybrid bio-composites is also carried out.

Ecological concern has resulted in a profound interest of the scientists, engineers and researchers in renewable materials to move towards greener future. To date, the development of natural fibre reinforced polymer composites and recyclable polymers are gaining high interest due to increasing concern and awareness to conserve the environment and uncertainty in the supply of petroleum-based resources. Therefore, the aspects of renewability, biodegradability (Ramesh, 2016), sustainability, eco-friendly, recyclability (Sreenivasan et al., 2015) and environmental issues (Nallusamy and Majumdar, 2016; Bhoopathi et al., 2017), are vital in ensuring a better future. One of the solutions is to reduce the consumption of synthetic materials. In parallel with this aim, natural fibres are finding uses as the substitute materials as reinforcement in polymer composites to the synthetic fibres. These combined efforts are due to the advantageous features of the natural fibres relative to the counterpart in the aspect of biodegradability, renewability (Zini and Scandola, 2011), recyclability, abundant, permeability, corrosion resistance, high degree of flexibility, non-toxicity, good insulation property (Nguong et al., 2013; Saba et al., 2014), non-irritation to the skin, no allergic effects, competitive mechanical properties, reduced energy consumption, less abrasive to equipment, minimum waste disposal and also relatively cheap as the natural fibres are abundantly available (Anil et al., 2016; Thiruvasagam et al., 2016; Amir et al., 2017) and sustainable in production (Ticoalu et al., 2010; Bhoopathi et al., 2014). Many of natural fibres for example kenaf, jute, sisal, sugar palm, hemp, coir, abaca, pineapple leaf and kapok have been applied as reinforcement in polymer composite (Nguong et al., 2013). Moreover, natural fibres reinforced composite are extensively utilized especially as automotive components, consumer goods, and civil structures. Most of the synthetic fibres reinforced composites are costly and restricted to aerospace and army applications (Devireddy and Biswas, 2016) and as an alternative to synthetic polymeric fibres for application in engineering composites (Ronald et al., 2013).

However, there are drawbacks of natural fibres of being hydrophilic, poor wettability, high moisture absorption, and incompatibility with some of the polymeric matrices (Nguong et al., 2013; Saba et al., 2014; Dhar Malingam et al., 2018). The production and use of synthetic fibres create a lot of environmental issues. Synthetic fibres are replaced with natural fibres to reduce the cost of the composites without affecting the mechanical properties. Most of the researcher attempts were made to enhance the mechanical strengths of composites, fibre reinforcements and its matrix, new composite sample processing methods and new techniques in modelling (Bhoopathi et al., 2017). This can be overcome by surface modifications through chemical treatments. Previous researchers have performed chemical treatments such as mercerization, isocyanate, acrylation, permanganate treatment, acetylation and silane coupling agent to improve the surface roughness and compatibility between natural fibres and polymer matrix.

In fibre reinforced composite materials, the applied stress is distributed from the polymer matrix to the fibres through the shear mechanism. The stress transfer in a composite